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ABSTRACT

As part of the Department of Education's Office of Educational Research and Improvement's (OERI) Studies in Education Reform Program, SRI's Center for Technology in Learning has been conducting a national study of the role of technology in supporting education reform, especially constructivist, student-centered teaching methods and instructional uses of computers and other technologies. Case studies of nine sites that have been using technology in ways that enhance a restructuring of the classroom around students' needs and project-based activities form the centerpiece of the project. Discussions include: "Moving from Discrete Skills to Authentic Tasks"; "Case Study Examples of Authentic Classroom Projects"; "Teacher-Reported Effects of Technology Use," including "Enhancing Student Work," "Increases in Motivation and Self-Esteem," "Changes in Student and Teacher Roles," and "Importance for Low-SES Students"; and "Factors for Success." Exhibits include: "Exhibit 1: A Computer-Supported Collaborative Elementary School Project" and "Exhibit 2: Examples of Technology-Enhanced Activities." Across the case study sites, classrooms were found where technology was supporting constructivist goals by providing students with new capabilities and teachers with both stimulation for their thinking about activities and evidence of what highly motivated students can accomplish with technology. At the same time, only a minority of classrooms even approached the model of technology use in the reformer's vision for classrooms of the 21st century. A table outlines study sites and demography. (Contains seven references.) (MAS)

April 1995

TECHNOLOGY'S ROLE WITHIN CONSTRUCTIVIST CLASSROOMS

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SRI International

Presented as part of a symposium, *Teachers, Technology, and Authentic Tasks: Lessons from Within and Across Classrooms*, at the annual meeting of the American Educational Research Association, San Francisco, California, April 1995.

Technology's Role within Constructivist Classrooms

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The education reform movement challenges teachers to transform their practice by adopting high standards for all their students; new curricula emphasizing higher-order skills; constructivist, student-centered teaching methods; and—increasingly—instructional uses of computers and other technologies. The kind of student-centered constructivist classrooms that reformers advocate make far greater demands on teachers than do the more conventional, teacher-centered approaches (Knapp & Means, 1991), and adding technology to the mix introduces yet another set of requirements. Despite the odds, a growing number of teachers are rising to this challenge.

As part of OERI's Studies in Education Reform Program, SRI's Center for Technology in Learning has been conducting a national study of the role of technology in supporting education reform.[1] Case studies of nine sites that have been using technology in ways that enhance a restructuring of the classroom around students' needs and project-based activities form the centerpiece of the project.

In selecting schools for study, we gave priority to sites that have emphasized education reform (rather than technology for its own sake) and that provide challenging, authentic activities for students from economically disadvantaged backgrounds. As context for the descriptions of observed activities and reported effects, Table 1 provides descriptive data for the nine sites.

Moving from Discrete Skills to Authentic Tasks

In many classrooms, especially those serving students from low-income homes, academic content has been decomposed into discrete component skills that have no obvious connection with anything students do outside of school. (See also Means & Knapp, 1991.) This practice has negative effects on motivation and makes transfer of learned skills to real-world tasks unlikely (Resnick, 1987). We have argued elsewhere (Means et al., 1994) that from an education reform perspective, the critical transformation for classrooms is the shift from teaching discrete skills and information within specific subject areas to centering instruction around *authentic, challenging tasks*. When classroom activities are structured around long-term projects with an authentic purpose, the value of the project tasks is apparent, students are challenged by more complex content, and the so-called basic skills are dealt with in context, providing a motivation for

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Table 1
CASE STUDY SITES

Site	Level	Student Body	Setting	Region
A	E	25% free/reduced lunch; 89% minority; 25% ESL	Suburban	West
B (Network of 462 Schools	All	Varies across schools	Rural/Urban/ Suburban	Midwest
C	M	65% free/reduced lunch; 60% Hispanic	Suburban	Southwest
D	E	85% free/reduced lunch; 95% minority; 59% LEP	Urban	West
E	E	23% free/reduced lunch; wide SES range; 61% minority	Urban	West
F	E	100% free/reduced lunch; 86% Hispanic; 64% LEP	Suburban	West
G	M	80% free/reduced lunch; 67% male	Urban	North Central
H (School-Within-a-School)	S	40% free/reduced lunch; 35% African American	Urban	Midwest
I (School-Within-a-School)	M 4-6	77% free/reduced lunch; 71% African American; 27% Hispanic	Urban	Northeast

mastering the mechanics of writing, computation, and so on (as well as the tasks' higher-level aspects of analysis, synthesis, and design).[2]

Our observations across sites provided opportunities to see the difference between learning skills and engaging in technology use as isolated academic tasks and addressing those same skills in the context of meaningful projects. Tasks that were grounded in activities that were challenging and made sense to students elicited a much greater level of student interest and understanding, as well as higher self-imposed standards for quality.

For example, we observed fifth-graders working on a project to develop curriculum materials about the experiences of minority group members who overcame adversity to become leaders in their community. To obtain the tools they needed to develop a polished set of curriculum materials, the students used word processing to write a series of letters to local businesses requesting the donation of goods (e.g., camera mics,

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2 Long-term projects involve activities centered around a theme or goal and lasting for weeks or months, rather than a single class period. By "authentic" we mean tasks that have meaningful goals, from a student perspective, other than simply fulfilling a school assignment or earning a grade. The complexity and time demands of such projects require a flexibility of scheduling, which often becomes a major impediment, particularly at the middle and secondary school levels.

printing) and services (i.e., allowing themselves to be interviewed). As they wrote at the computers in pairs, students engaged in lively discussions regarding both the form and content of the letters, seeking out one another's input, and revising as they went. They put careful thought into how much and what kind of information to include (e.g., "We have to tell them who we are..."), as well as into how to present their requests in the most compelling fashion. The activity continued over multiple sessions across several days, culminating in the printing and the actual mailing of the letters. In contrast, at another site, middle school students participated in a 50-minute word-processing class that on one particular session focused on the writing of business letters. The teacher instructed the students to "just make up" the content (the example given was a request or a complaint to a fictitious business), placing the emphasis of her instruction and feedback on proper formatting and on the mechanics of using a word processor. Many students were at a loss for what to write as they struggled with the task of generating content in the absence of a meaningful context. Some students were visibly bored by the activity, and there was little discussion among the students regarding their work.

Although the use of technology does not automatically make a task authentic (as illustrated in the lesson on business letters above), technology can significantly enhance authentic, extended classroom projects. The use of technology tools increases the "real-life" feel of classroom tasks. As one teacher put it, students are motivated when they sense that they are "using real tools for real purposes." Being able to access the software tools that are used by professionals for similar tasks allows students to aspire to work processes and a quality of product that more closely reflect what they see and know of the outside world. Bringing external resources into the classroom through the use of telecommunications adds another dimension of authenticity to their work as students are able to link with real people and places, as well as public databases (e.g., NASA, NOAA) and information sources. Technology tools support the accomplishment of more complex tasks by handling portions of the task that otherwise would be excessively tedious or difficult (e.g., the use of calculators allows students to concentrate on math concepts rather than the details of calculation for large numbers). Technology supported tasks also lead naturally to divisions of labor, with different students specializing in different components of the task or in different technologies and with supports for collaboration through the sharing of student thinking and work in progress (as in the Computer Supported Intentional Learning Environments described in Exhibit 1).

Case Study Examples of Authentic Classroom Projects

The case study sites provided examples of classrooms undertaking extended projects with support from technology. Our school panelists will describe two such projects at length: one in which students plan and build scale models of a city of the future for their local area and one in which two classes studying the topic of culture each design and develop artifacts for a hypothetical culture for the other class to excavate and interpret.

Among other examples in our case studies were students in a middle school industrial arts class who form companies and produce and sell products such as wine racks, cabinets, or folding wooden stools. To enact the various operations of the company, students elect company officials and divide into work teams. Many of the team activities are supported by technology. For example, the Finance team uses computer spreadsheets to find the lowest-cost materials and to create financial statements for the company. The Research team uses drafting software in drawing up design plans. The Marketing team uses the word processor in creating advertisements and product descriptions. A video camera is used in creating commercials for the product; the commercials are then aired over the school's broadcast system.

Exhibit 1

A Computer-Supported Collaborative Elementary School Project

During the 1993-94 school year, two 5/6 CSILE classrooms at a California elementary school organized their curriculum and a series of project-based activities around the interdisciplinary theme of "ancient civilization." For the initial extended project, they drew from a simulation curriculum called DIG (developed by Interact), in which students invent their own ancient civilization, creating artifacts, symbols, and values. The project began in September with the class discussing "what makes a culture":

First we talked about culture, the different aspects that make up culture, which we call culture universals. So we looked at housing, language and food, transportation, values, government system. We looked at it within our own culture and then we invented our own culture. —Elementary school teacher

Working in small groups, students in each classroom created their specific cultural universals on the basis of the overall values and the geographic location that was decided on by the class as a whole. One class selected the care of the environment as their culture's overriding value or "theme," and they located their culture in the rain forest. The students studied images of animal and plant life on a rain forest laserdisc to ensure that whatever they were making was compatible with a rain forest environment. Once these aspects of the culture were decided, students began generating their cultural universals.

Use of Computer-Supported Intentional Learning Environments (CSILE) helped students organize and extend their thinking through collaboration with their peers. Using CSILE as a shared database, students wrote text and created graphics that described and depicted their cultural universals. They created links between entries that were conceptually connected (most often linking a text with a corresponding graphic image). Many of the Spanish-speaking students entered their notes in their primary language, which they then linked to an English translation. Throughout this process, students read and responded to one another's emerging plans and ideas using "helpful, thoughtful" comments.

CSILE entry on "number system":

This is the slaminan's number system. It is a basic
10 number system too. It has a pattern to it. The
number of lines increase up to five then it goes
upside down all the way to 10.

[Above text entry is linked to an illustration of the number system]

Comment posted on CSILE from the "ritual group":

We all like the number system, but we want
to know how the number 0 looks like, and you can
do more numbers not just ten like we have right now.

6

Exhibit 1 (concluded)

As each group created their piece of the culture (e.g., clothing, language, housing), they needed to determine whether it was consistent with the overall culture. This required a high level of coordination and communication between the individual working groups. CSILE facilitated this process by providing students with a means for sharing their developing ideas quickly and easily.

The ideas developed in creating hypothetical cultures and skills in using CSILE were later applied to the study of real cultures and of immigration. Students and teachers generated challenging topics about the culture under study (e.g., "What did the ancient Egyptians do to write numbers?" "What were their laws and government?"). A student who initiated a topic would be prompted by CSILE to figure out specific things that needed to be learned to address the topic. By posting the inquiry on-line, the student would get help from other students in figuring out ideas (actions) and resources (where to go for more information). Students would make on-line notes of information on the topic as they collected it, stimulating other students to add more information and interpretations. As students became more adept with the process of collaborative knowledge building through CSILE, their dialogues took on an impressive level of sophistication.

A collaborative project between a local mall and sixth-grade classes in a community serving a large migrant farm worker population provided students with opportunities to learn about retail sales. Students conducted a market survey, polling their parents about what mall service they would like to see provided. On the basis of the survey, students decided that a gift-wrapping service was the most viable use for the kiosk space to be made available to them. Students conducted follow-up surveys with focus groups, researched the cost of supplies, and drafted letters to solicit funds. Sixth-graders in the 4/5/6 class at one of our sites attended this project's training sessions at the mall and returned to teach the rest of their class what they had learned. The students, who are just transitioning to the use of English in the classroom, exercised language and math skills as they gathered information over the phone, used word processing to write letters soliciting donations, and developed spreadsheets to assist in cost comparisons and budgeting.

High school students in a technology-rich school-within-a-school program developed video portfolios to demonstrate to prospective employers and college admissions personnel the skills and interests they had acquired in the program. The 5-minute tapes made by individual students highlighted marketable technology and problem-solving skills that are not easily captured in a text resumé.

In addition to projects in which students undertook authentic tasks, we observed classrooms where assignments were more traditional, but technology tools were used to support these activities and enable the production of more professional products, in much the same way that such tools facilitate work in offices and research centers. In one middle school, for example, students in an eighth-grade research class prepared multimedia presentations on topics such as sea turtles or an Indian tribe's protests against storage of spent nuclear fuel rods on their land. Typically, students would choose to photocopy written material to highlight for later reference, gather information from a CD-ROM, conduct a telephone interview with an informant, use the computers in the Writing Lab to prepare text

portions of their presentations, and perhaps use the scanner, the interactive videodisc, or *HyperCard* in another computer lab to incorporate graphics, sound, or animation. The technology resources available raised the standard for student products, leading to the incorporation of a wider range of information and developing a stronger awareness of presentation values.

In a senior high school electronic research class, students learned to use electronic research tools such as DIALOG searches and Veronica searches with Gopher on the Internet. They then practiced using the tools to collect, analyze, and synthesize information on themes such as student rights, habitats, pollution, and AIDS research. One group of students chose to search out all the Supreme Court decisions regarding student rights in preparation for writing and presenting position papers on the topic. Another project involved designing a plan for colonizing a planetary object of the students' choice. Students used the Internet to search for information on their planet and download digitized graphics such as images of Jupiter's moons. Using all these data, they wrote reports about how they would colonize the planet.

Teacher-Reported Effects of Technology Use

Teachers in the case study classrooms were asked to describe the effects that the introduction of technology had on their classrooms. Summaries of teacher comments were analyzed using THE ETHNOGRAPH, a qualitative analysis program (see Ruskus & Luczak, 1995, for a description of the methodology). As shown in Table 2, teacher-reported effects fell into three general categories:

- Improvements in student skills and products
- Increases in student motivation and self-esteem
- Increased collaboration and changes in student and teacher roles within the classroom.

Enhancing Student Work

Teachers reported that use of software tools enabled students to go farther than previous classes had without technology in a whole variety of curriculum areas. Exhibit 2 contains two such examples, the City-Building Project alluded to earlier and a middle school mathematics teacher's description of how software tools helped her students understand graphs and alternative forms of data presentation at a deeper level.

The number of times a specific theme appeared in the teacher interviews was tallied, using the printouts from THE ETHNOGRAPH.[3] Among the more specific expressions of the general theme of technology's positive impacts on the quality of student work and the complexity of tasks that students could handle were "have acquired technical skills" (cited by 15 of 17 case study classroom teachers), "can accomplish more complex tasks" (14 of 17), and "higher-quality products" (7 of 17).

Writing and desktop publishing were widely cited as areas that had been positively affected by the use of computers. Teachers reported that students produced higher-

[3] The number of times a particular theme appears across the teacher interviews provides a general sense of the theme's prominence in the teachers' thinking but should not be interpreted as a frequency estimate for the teacher population. The themes themselves were derived in part from an inductive analysis of the teacher responses; the counts for the themes' appearances across teacher interviews were not derived from a structured survey in which each teacher gave a response to a probe for each effect.

quality texts when writing with the word processor and were often more willing and able to edit their texts in this context. At one of the high schools participating in a networking project, where students use the Internet to research report topics, both the students and the teachers said that the reports were of higher quality in terms of the breadth, recency, and comprehensiveness of the information incorporated.

Table 2
TEACHER-REPORTED EFFECTS OF TECHNOLOGY ON STUDENTS

Reported Effect	Number Reporting[a]
Improvements in Student Performance	
Technical skills	15
Accomplishment of more complex tasks	14
Increased use of outside information resources	10
Enhanced creativity	9
Improved design skills; ability to present information better	7
Improved understanding of audience needs	7
Higher-quality products	7
Increased likelihood of editing own writing; better editing skills	4
Greater consideration of multiple perspectives	3
Improved oral communication skills	2
Motivational Effects	
Increased motivation	16
Heightened self-esteem	11
Improved behavior, such as attendance, time on task	5
Changes in Student and Teacher Roles	
More collaboration with peers; peer teaching	13
Better self-regulation of own learning	11
Students teaching teachers	5

[a] Out of 17 case study teachers.

Subthemes in the area of higher-quality work are that technology increases use of outside information sources (cited by 10 of 17 teachers) and prompts both greater consideration of multiple perspectives (3 of 17) and an improved understanding of audience needs (7 of 17). Perhaps as a result of these effects, teachers felt that use of technology enhances creativity (9 of 17), improves design skills and the ability to present information well (7 of 17), and promotes better oral communication skills (2 of 17). Multiple media give students choices about how best to convey a given idea (e.g., through text, video, animation). Experiences in developing the kinds of rich, multimedia products that can be produced with technology, particularly when the design is done collaboratively, give students exposure to their peers' reactions to their presentations, thus supporting their development of design and presentation skills.

Exhibit 2

Examples of Technology-Enhanced Activities

A Middle School Mathematics Unit

A middle school math teacher describes how technology supports enable her students not only to produce higher-quality graphs but also to understand graphs at a deeper level and to be able to examine the relative strengths and weaknesses of different graphic representations.

In an activity designed to introduce students to the use of spreadsheets to calculate, analyze, and present quantitative data, students first estimated the length of various parts of their own bodies (e.g., wrist circumference) and then made actual measurements. Both sets of data were entered onto a spreadsheet, from which students then began to experiment with different ways of representing the data. Because the physical production of the graphs was handled by the computer, students could focus on making the conceptual link between the spreadsheet data and the visual representation. They worked collaboratively to determine what information to display and how best to display it.

After trying a variety of representations (e.g., pie, line, and bar graphs), students were able to discuss with insight the advantages and disadvantages of each type of graph for different types of data sets (e.g., pie graphs can display only one variable).

The City-Building Project

The students in a mixed-age (8 to 10) team-taught class at a Los Angeles magnet elementary school spend a good part of their year on a project designing a city of the future for the urban area in which their school is located. Students divide into neighborhood groups that must work together to decide what will be built in their area of the city. Each child is responsible for an individual parcel within the neighborhood. Students also have membership in city commissions (e.g., Environment, Building and Safety), which may pass regulations that apply to all the neighborhoods. In the case of a controversial issue (e.g., treatment of the infirm elderly), students may develop a survey and administer it to their classmates to determine public opinion.

With one computer for every two students in the class, students are able to use technology when they feel it would support their assigned tasks. Students use word processing software in writing their city plans and descriptions. A drawing program (*Canvas*) is used when they need to design objects and buildings. *HyperCard* stacks and animations are used to illustrate the work of the various city commissions and neighborhood groups. Spreadsheet software is useful when it is time to calculate the effect of a decision under consideration on some variable (e.g., the effect of a building height limit on the number of residents that can be accommodated) and to graph survey responses. A portion of the city-building activities were videotaped and edited to produce *QuickTime* clips for a multimedia record of the project.

Not surprisingly, the greater use of outside information sources was cited most often in classrooms that had incorporated telecommunications activities, but other classes used technologies such as satellite broadcasts, telefacsimiles, and the telephone to help provide access to external sources of information (and to find wider audiences for their work). Schools with links to the Internet reported that the network brought "the outside world" into the classroom, enabling students to gather data directly from a wide variety of sources and to learn about life beyond the classroom walls through interpersonal communication with e-mail participants from around the world. Students at a school in Harlem who were studying Ireland for their schoolwide multicultural fair, for example, used the Internet to interview Trinity College students and to obtain information on historical artifacts from the college's database.

> *Sometimes children . . . are very isolated because they don't get to go many places. But through this communication over the computer they are able to relate that Ireland isn't just a place on a map but that there are people living there, and through e-mail they get a response. A lot of them have pen pals all over the world.* —Elementary school teacher

When students conduct searches on the Internet, they are faced with the reality of many different sources of information on any given topic and are likely to encounter varying perspectives on any given subject. Engaging in electronic-mail communication with individuals from distant locations further increases the likelihood of communication with people with perspectives unlike their own.

> *It makes kids realize that information is happening right now and it's not just in a textbook. And text books can be wrong. And there's always a perspective in a textbook. . . : let's get it from someone who is really living there instead of from a textbook.* —Elementary school teacher

Increases in Motivation and Self-Esteem

The most common—in fact, nearly universal—teacher-reported effect on students was an increase in *motivation.* Sixteen out of 17 case study teachers reported that technology increased their students' motivation level, 11 said they had observed increased self-esteem, and 5 talked about improved classroom behavior.

Teachers discussed technology's effect on motivation from a number of different perspectives. Some described increased motivation with respect to working in a specific subject area, for example, a greater willingness to write or to work on computational skills. Others spoke in terms of more general motivational effects—student satisfaction with the immediate feedback provided by the computer and the sense of accomplishment and power gained in working with technology:

> *Kids like the immediate results. It's not a result that you can get anywhere else except on the computer. . . . For them it really is a big deal—much more so than I ever thought it was going to be.* —Elementary school teacher

> *Technology is the ultimate carrot for students. It's something they want to master. Learning to use it enhances their self-esteem and makes them excited about coming to school.* —Fifth-grade teacher

The computer has been an empowering tool to the students. They have a voice, and it's not in any way secondary to anybody else's voice. It's an equal voice. So that's incredibly positive. Motivation to use technology is very high. —Elementary school teacher

Teachers also frequently cite technology's motivational advantages in providing a venue in which a wider range of students can excel. Compared to conventional classrooms with their stress on verbal knowledge and multiple-choice test performance, technology provides a very different set of challenges and different ways in which students can demonstrate what they understand (e.g., by programming a simulation to demonstrate a concept rather than trying to explain it verbally). Teachers and students are sometimes surprised at the level of technology-based accomplishment displayed by students who have shown much less initiative or facility with more conventional academic tasks. For many students, the feeling of mastery, as well as the social recognition that often accompanies such accomplishments, can truly make a difference in their sense of efficacy as learners.

Both the increased competence students feel after mastering technology-based tasks and their awareness of the value placed on technology within our culture appear to lead to increases in students' (and often teachers') sense of self-worth.

I see more confidence in the kids here. . . . I think it's not just computers; it's a multitude of things, but they can do things on the computers that most of their parents can't do and that's very empowering and exciting for them. It's "I can sit down and make this machine pretty much do what I want to," and there's something about that that gives them an extra little boost of, "Wow, I'm a pretty special person." —Elementary school teacher

Teacher reports regarding increased student motivation and self-esteem were supported by our classroom observations. Throughout our site visits, students were eager to share their computer-supported activities and products with us. They were obviously proud of their technical skills and of the type of work that they are able to accomplish with technology. Students commented during interviews that using computers made them feel special and important. More often than not, students in our focus groups reported that they preferred working at the computer to using other, more traditional tools (e.g., textbooks, pencils and paper).

Changes in Student and Teacher Roles

In describing how the introduction of technology had affected their students, 13 of 17 case study teachers described an increase in collaboration and more peer teaching among their students; 11 noted that students were more inclined to monitor and regulate their own learning; and 5 reported that there was an increased incidence of students' teaching teachers. These themes are indicative of a fundamental shift of classroom organizational structures and roles.

Most of the long-term, technology-supported projects described earlier were performed by groups of students working collaboratively. In addition to these cooperative learning assignments, we observed also considerable tutoring around the use of technology itself. Collaboration is fostered, for obvious reasons, when students are assigned to work in pairs or small groups at a limited number of computers. But even when each student had a computer, teachers noted an increased frequency of students'

helping each other. Technology-based tasks involve many subtasks (e.g., creating a button for a *HyperCard* stack or making columns with word processing software), leading to situations where students need help and find their neighbor a convenient source of assistance. Students who have mastered specific computer skills generally derive pride and enjoyment from helping others.

In addition, the public display and greater legibility of student work on a computer or in a video creates an invitation to comment. Students often look over each other's shoulders, commenting on each other's work, offering assistance, and discussing what they are doing.

> *I've also seen kids helping each other a lot at the computer. The ones that pick it up faster, they love teaching it to someone that doesn't know it yet.*
> —Fourth-grade teacher

> *The ones who have used it from the beginning have become peer coaches.*
> —Fifth-grade teacher

One of our teacher informants made the point that the technology invites peer coaching and that, once established, this habit carries over into other classroom activities:

> *It's a much more facilitating atmosphere because the kids help each other so much on the computer. It changes the style and the tone of the classroom a lot.* —Elementary school teacher

We observed classrooms in which the teacher had made the shift from being the dispenser of information to acting as facilitator, setting project goals and providing guidelines and resources, moving from student to student or group to group, providing suggestions and support for student activity. The majority of time in these classrooms was devoted to independent and collaborative projects; technology-based activities typically comprised one or more of a larger number of simultaneous activities or "rotations."

Project-based work and cooperative learning approaches require this change in roles, whether technology is used or not. However, technology use is highly compatible with this new teacher role. Several teachers reported that technology led them to give their students more control after they witnessed what students could do with technology and how they were willing and able to take responsibility for teaching themselves and one another.

> *I truly think that technology has forced us to rethink the way we relate to kids in the classroom. It changes kids' roles so that they become more active and provides them with more kinds of exciting activities, which in essence become more challenging.* —Middle school teacher

> *I was definitely a sage on the stage when I started and taught math for 12 years, and I was the center of the curriculum and the center of learning, I thought. And as soon as I got computers, I found out, you know, I really don't need to be up there showing them everything. There's a lot of things they can learn on their own. In fact, they're better at learning things on their own and discovering things.* —High school teacher

In addition, technology use often puts teachers in the role of learner alongside their students. This is a big change from the traditional role of the teacher as the one with all

the knowledge and right answers. Instead, students are given the chance to see their teachers struggle with the acquisition of a new set of skills. Teachers who are not threatened by this change in roles report that the experience sensitizes them to the learning process in unexpected ways, giving them new insights into their students as learners. Engaging in the process of exploring technology with their students further provides teachers with an opportunity to demonstrate aspects of problem solving and learning that are rarely made visible in more product-oriented classrooms. Moreover, when the venue for work is technology, the teacher often finds himself or herself joined by many student coaches, who become actively involved in teaching other students or, indeed, the teacher.

Importance for Low-SES Students

The kinds of technology-supported constructivist activities observed in these classrooms are particularly important for the instruction of students from low-income or non-English-speaking backgrounds. The typical instruction received by these students emphasizes basic skills, with more complex tasks broken down into such small pieces that any sense of purpose or context is lost. Often, students labor year after year to demonstrate mastery of the more mechanical components of writing, mathematics, and reading, with little opportunity to show what they can do in the areas of reasoning, design, and expression. Organizing classrooms around complex, authentic tasks supplies this opportunity. Further, the new skills and multiple modalities involved in technology-supported design and development tasks make it possible for students to contribute to a group and to show what they know in a variety of ways.

The disparities in access to technology in the home for students from varying economic backgrounds underscore the importance of providing these experiences in classrooms serving students from low-income homes. Administrators and teachers at many of our case study sites were strong advocates for infusing technology into the classroom experiences of students from low-income homes. Although such initiatives can have a major impact, we should not expect them to completely eliminate the technological advantage of those students who have access to technology and exposure to technology-using role models in the home. In addition to developing policies to equalize opportunities for in-school technology access for all students, a number of schools worked on norms for cooperative technology work that would ensure that all children get opportunities to take the lead. In several classrooms, we observed students working in pairs at computers as they regulated their own sharing of roles, trading off control of the keyboard without external prompting. Several other schools tried to mitigate the differences in technology background stemming from differential experience with computers in the home by instituting take-home computer programs.

Factors for Success

We have written elsewhere about the factors that emerge as most important in fostering a successful implementation of technology-supported reforms at the school level (see Means, Olson, & Ruskus, 1995). Here we consider the related issue of factors correlated with the provision of classroom activities congruent with a constructivist model.

First, classrooms where we observed exemplary technology-supported constructivist learning had been involved in project-based and collaborative learning for some time. Thus, teachers were not simultaneously embarking on the introduction of technology and an entirely new structure for classroom organization. They were accustomed to dividing

the class into subgroups for project activities, and students were used to working with each other. In classrooms where there was extensive use of collaborative project work, there had been explicit instruction on issues of how to work together. Sometimes the instruction stressed specific roles for work groups; sometimes it focused on standards of dealing with each other politely and empathetically, sometimes on dealing with conflicts, other times on how to give constructive criticism. Having been through this process, both students and teachers had a set of skills and expectations that prepared them for collaborative projects with technology.

Second, in many cases. the most extensive and exciting projects were conceived and executed collaboratively by more than one teacher. In some cases, as in the case of the practitioners on this panel, the teachers worked as a team; in other cases, teachers taught separate classes but collaborated extensively. At some sites, the collaboration occurred not with a fellow teacher but with a research group interested in testing the application of a new technology or instructional approach. The opportunity to plan a project with a colleague, to receive feedback for one's ideas, and to receive additional input appears to spur teachers on to more ambitious projects and to greater coherence and quality in their instructional program.

Third, classrooms are more likely to progress toward the reformer's vision of technology-supported authentic projects when there is a critical mass of technology, allowing each student to have access for a minimum of several hours a week. Whether the equipment is physically housed in the regular classrooms, in mobile labs, or in a separate laboratory, students and teachers need frequent, convenient access. At the same time, we replicated the observation made by others that having too much technology can be a deterrent to cooperative learning: the need for students to share computers or other equipment has had serendipitous effects on the amount of collaboration in many classes. However, having so few computers that only one or two are available at any given time makes it very difficult to implement a rotation schedule with technology support for a significant proportion of the class.

Fourth, successful technology-supported constructivist projects were more common within schools that provided supports for them—both technical support and supported time for learning and collaboration. Quite a bit of technical support is needed in schools where all or most teachers are using technology, particularly if new or experimental systems are involved or extensive use is made of computer networks. Technical support needs to be not only easily accessed but also unthreatening. Making teachers feel embarrassed about what they don't know about baud rates or network architecture is hardly the way to induce them to use technology in their classrooms. Although some sites attempted to make do with help from a knowledgeable teacher volunteer or with part-time services from a district technology coordinator, such arrangements were often unsatisfactory. Like all of us, teachers trying to use technology in their classrooms want technical help *on demand*. Controlling a classroom full of students in the midst of some activity that requires technology when the system goes down requires flexibility and skill. If technical problems arise frequently and teachers have to wait hours, days, or weeks to get them resolved, they will abandon their efforts to incorporate technology.

At least five kinds of technical assistance are necessary:

- Help in planning for technology uses and acquisitions
- Training in how to use new hardware and software
- Demonstrations and advice on how to incorporate technology into instruction
- On-demand help when software problems or hardware failures arise
- Low-level system maintenance.

Several technology coordinators felt that the most important aspect of their role over time was assisting teachers with the integration of technology into the curriculum. One technology coordinator described her role as shifting to that of "technology curriculum resource specialist." This latter role requires much more than technical troubleshooting. It requires ongoing communication (including time to meet and plan together) as technology coordinators collaborate with teachers in identifying appropriate matches between instructional needs and potential uses of technology. This process can lead to exciting new ideas and approaches, as teachers have the opportunity to rethink their instruction in relation to software tools and technology capabilities that they otherwise might not have been aware of.

Finally, given the many competing demands for their time, teachers are more likely to persist with the development of technology-supported constructivist projects when their efforts are recognized and encouraged by their colleagues and school administrations. Mini-grant programs, support for professional activities, and recognition programs can all help, but the greatest and most important support appears to be supported time for working on technology-related activities and collaborating with colleagues in school and out of school.

Conclusion

Across the case study sites, we found classrooms where technology was supporting movement toward these goals by providing students with new capabilities and teachers with both stimulation for their thinking about learning activities and evidence of what highly motivated students can accomplish with technology tools. At the same time, only a minority of classrooms even approached the model of technology use in the reformer's vision for classrooms of the 21st century. These were classrooms where teachers were already open to project-based, student-centered approaches and where the school environment provided supports in terms of opportunities for teacher collaboration, adequate levels of technology access, technical assistance and supported time for learning about technology, and recognition and encouragement for technology-supported projects.

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